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A Comprehensive Review of Curcumin: Therapeutic Potential and Drug Delivery Approaches

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ABSTRACT

Curcumin, a strong natural substance derived from Curcuma longa, has received a lot of interest due to its remarkable therapeutic potential in the treatment of cancer, cardiovascular illnesses, and neurological disorders. However, its clinical applicability has been limited due to issues such as low bioavailability, instability, and rapid metabolism. Nanotechnology has the potential to overcome these constraints by increasing curcumin's solubility, stability, and bioavailability. This review looks at current advancements in nanocarrier-based curcumin delivery systems such as nanoparticles, liposomes, niosomes, nanoemulsions, films, and transdermal patches. Several nanoparticle-based formulations, including silica nanoparticles, liposomes, and hydrogels, have showed improved drug stability, targeted distribution, and controlled release, making curcumin more effective in treating complicated disorders. Liposomes, for example, have been tailored to target cancer cells, whereas niosomes show promise for crossing the blood-brain barrier in neurological applications. Furthermore, curcumin-loaded nanofibers and composite films offer long-term release and therapeutic effects in wound healing and cancer treatment. Nanoemulsions and emulsions increase the solubility of curcumin, while polymeric micelles and hydrogels allow for controlled drug release for targeted cancer therapy. In addition, curcumin-based transdermal patches hold great promise for localized drug delivery. Combining these advanced delivery systems with curcumin's therapeutic properties holds great promise for improving its clinical efficacy, enabling more effective treatment strategies for various diseases. Despite significant progress, further research is needed to optimize these formulations and address challenges such as expanding clinical use and improving patient adherence to treatment.

Keywords: Curcumin, Nanocarriers, Nanoparticles, Liposomes, Niosomes, Nanoemulsions, Nanofibers, Drug Delivery Systems, Bioavailability, Controlled Release, Cancer, Neurological Disorders, Transdermal Patches.

INTRODUCTION

For quite a while, customary clinical frameworks like Ayurveda and Chinese medication have utilized curcumin, the imperatively dynamic fixing in turmeric (Curcuma longa). Frequently alluded to as the "splendid zing," turmeric has been utilized for its antimicrobial, quieting, and malignant growth preventive characteristics. It is encouraged in Ayurveda to screen illnesses, for example, respiratory issues, stomach-related issues, and joint agony[1,2]. Turmeric has likewise been utilized in Chinese medication to advance injury mending and blood stream[3].

Curcumin has acquired consideration in present day medication because of its possible remedial purposes in constant circumstances like malignant growth, diabetes, coronary illness, and neurological problems[4,5]. The ability of Curcumin in flagging pathways including with the atomic component kappa B, making it a promising component for remedial intervention[6].Still the low bioavailability of curcumin is still a significant barrier of its clinical success.

Chemical Structure of Curcumin

Curcumin is a polyphenolic compound with the subatomic condition C21H20O6 and a sub-atomic load of 368.38 g/mol. It basically comprises of two sweet-smelling rings associated by a seven-carbon chain containing keto and enol

gatherings, which are added to its real tautomeric bonds[7]. This construction is liable for its cell upgrade and its capacity to rummage free extremists.

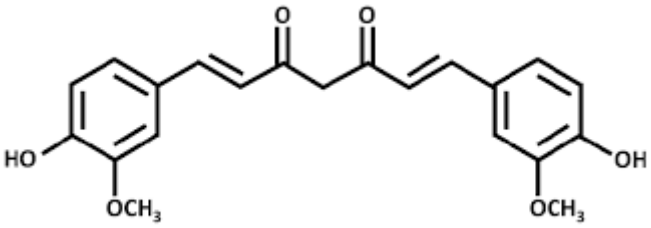

Fig 2: Chemical structure of Curcumin

Drug Profile

Curcumin has various different type of pharmacokinetic properties, some properties include its dissolvability in fluids that is very low (< 0.01 g/mol) and its faster metabolic turnover, due to this its basal bioavailability is restricted. Irrespective of these challenges, the security profile is outstanding, with no harmfulness that shows up on dosages up to 12 g/day in people[8].

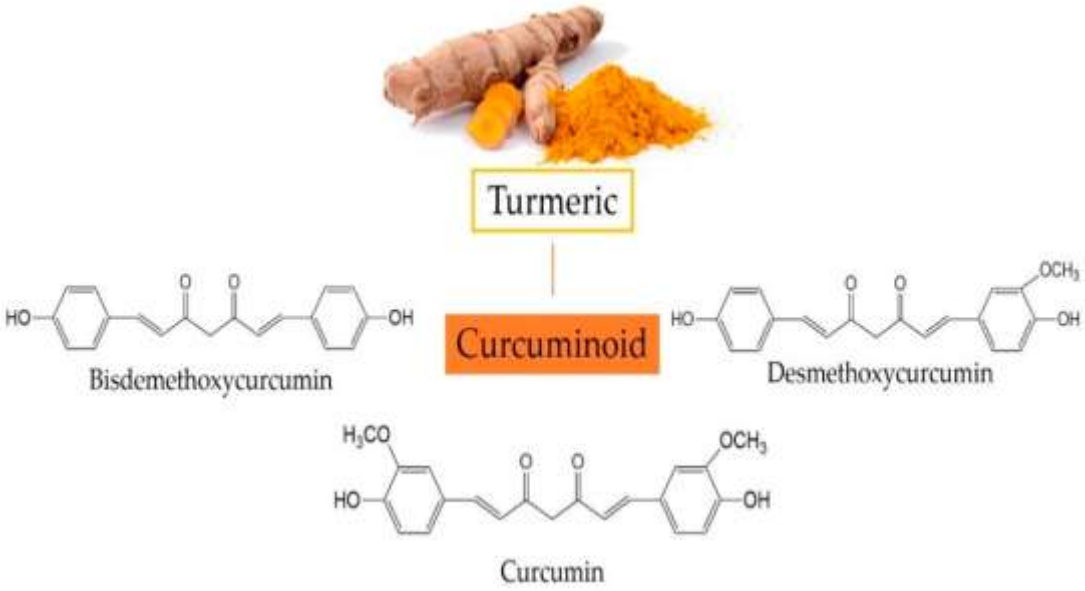

Fig 3: Three major curcuminoids in turmeric and their chemical structures.

Physicochemical Properties

Curcumin is hydrophobic, with a logP worth of 3.29, showing lipophilicity. It is steady at acidic and impartial pH, yet goes through changes under solvent circumstances[9]. These properties are fundamental in the plan of medication conveyance frameworks to work on their security and dissolvability.

Biological Activities

Curcuminproposes different regular exercises, including quieting, cell fortifying, antimicrobial, and anticancer impacts. It influences sub-atomic targets like cyclooxygenase-2 (COX-2), interleukin-6 (IL-6), and cancer rot factor alpha (TNF-α), demonstrating its advantageous potential[10,11].

Therapeutic Potential of Curcumin

Curcumin has shown beneficial outcomes specifically regions like malignant growth, cardiovascular sicknesses, diabetes, and neurological issues. Its anticancer properties are connected to its capacity to prompt apoptosis, cause cell cycle capture, and repress angiogenesis in impacted cells[12,13]. Also, curcumin has been read up for its neuroprotective impacts in patients with Alzheimer's and Parkinson's by diminishing oxidative pressure and amyloid plaque development[14,15].

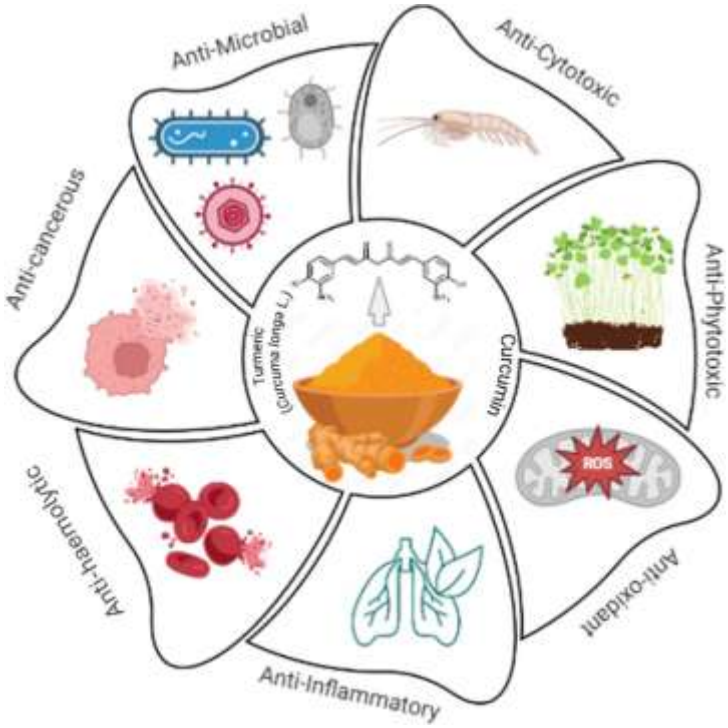

Fig 4: Therapeutic benefits of curcumin

Regardless of its certified advantages, curcumin faces difficulties in clinical use, fundamentally because of its low bioavailability. Issues like unfortunate solvency, quick digestion, and restricted fundamental dispersion upset its adequacy. Methodologies, for example, nanoparticles, liposomes, and micelles have been created to address these difficulties[16,17].

Drug Delivery Challenges and Solutions for Curcumin

Bioavailability Issues

Curcumin exhibits promising therapeutic potential; however, its clinical applications are severely hindered by bioavailability issues. The primary challenges include poor aqueous solubility, rapid metabolism, and low systemic absorption[12,18]. Curcumin's hydrophobic nature limits its solubility in physiological fluids, leading to inadequate absorption in the gastrointestinal tract. Furthermore, once absorbed, it undergoes rapid metabolism in the liver and intestinal mucosa, forming inactive metabolites such as glucuronides and sulfates[19,20]. These factors significantly reduce its plasma concentration and therapeutic efficacy.

To Address These Challenges, Several Strategies Have Been Developed:

- **Use of Adjuvants:** Compounds like piperine, a bioenhancer, inhibit the metabolism of curcumin and improve its bioavailability by up to 2000%[21].
- **Lipid-Based Systems:** Liposomes and solid lipid nanoparticles enhance solubility and stability by encapsulating curcumin in a lipid matrix[22].
- **Polymeric Nanoparticles:** These systems provide controlled release and target-specific delivery, improving circulation time and bioavailability[24].
- **Micelles and Cyclodextrins:** Surfactant-based micelles and cyclodextrin inclusion complexes enhance water solubility and protect curcumin from degradation[24,25].

Need for Improved Delivery Systems

The limitations of curcumin's bioavailability underscore the urgent need for advanced drug delivery systems to enhance its therapeutic efficacy. These systems not only address solubility and stability concerns but also enable targeted and controlled release, minimizing off-target effects[16].

Advanced Delivery Systems for Curcumin

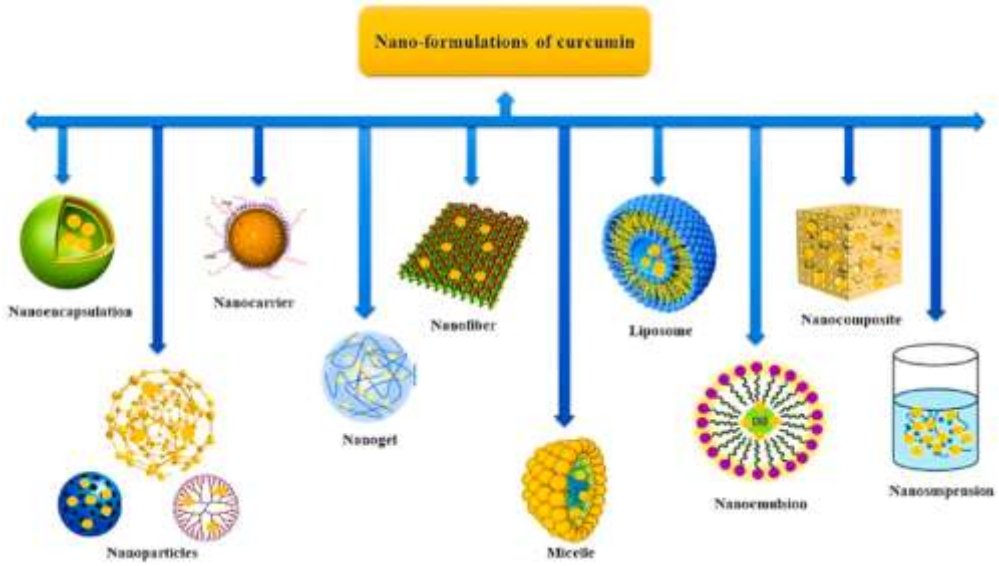

Fig 6: Nano-formulation of Curcumin

1. **Nanoparticles:** Polymeric and lipid nanoparticles increase curcumin's stability and allow sustained release. For instance, polymeric nanoparticles like PLGA (poly-lactic-co-glycolic acid) improve drug residence time and intracellular uptake[26].
2. **Liposome:** By encasing curcumin in a phospholipid bi-layer, liposomes postpone its half-existence and guard it from enzymatic breakdown[27].
3. **Hydrogels:**Curcumin's energy below physiological instances are progressed with the aid of using biocompatible hydrogels, which proposition managed discharge[28].
4. **SNEDDS:**These frameworks altogether paintings at the dissolvability and retention of curcumin with the aid of using speaking with gastrointestinal drinks to form exceptional oil-in-water emulsions[29].
5. **Nanofibers:**Curcumin is privately conveyed with the aid of using electrospun nanofibers for malignant boom and wound mending applications[30].

Challenges and Solutions for Curcumin Bioavailability

Table 1: Summary of Delivery Systems and Their Applications

Delivery System	Advantages	Applications
Nanoparticles	Improved stability, controlled release, better bioavailability	Cancer therapy, wound healing
Liposomes	Targeted delivery, solubility enhancement	Neurological and cancer treatments
Hydrogels	Biocompatible, sustained release	Skin disorders, localized treatment
Transdermal Patches	Sustained drug release, targeted treatment	Pain management, chronic inflammation
Nano-emulsions	Increased solubility, long-term stability	Oral drug delivery
Nanofibers	High encapsulation, sustained release	Chronic diseases, wound healing

These upgrades display that curcumin's conveyance barriers is probably survived, beginning the entryway for its fruitful software in medical settings.

Formulation Strategies for Curcumin

Nanoparticles

Nanoparticles are one of the most encouraging conveyance frameworks for curcumin because of their capacity to upgrade dissolvability, security, and bioavailability. There are two principal kinds of na-noparticles utilized for curcumin conveyance: polymeric nanoparticles and lipid-based nanoparticles.

This data gives an in depth define of various nanoparticle info meant to improve the conveyance and restorative viability of curcumin. These formulations use diverse methods, for example, neutron reflectometry, nuclear electricity microscopy, flimsy movie hydration, and excessive-gravity innovation to create nanoparticles with unique properties, inclusive of upgraded solvency, managed discharge, and im-proven bioavailability.Polymers applied in those plans fluctuate, with substances like chitosan, poly (lactic-co-glycolic corrosive), and silica nanoparticles being ordinary decisions.Applications variety exclusive restorative regions, inclusive of malignant boom treatment, neurological sicknesses, and twisted mending, with distinct conveyance frameworks regularly lev-eraging receptor-express atoms like folic corrosive for progressed particularity.Key at-recognitions of those info include excessive exemplification effectiveness, supported drug discharge, and cytotoxic effects for ailment cells, for sure plans likewise evil presence strating antimicrobial and mitigating exercises. This combination manner to cope with curcumin-primarily based totally nanoparticle plans capabilities their promising capability in conquering curcumin's intrinsic bioavailability demanding situations and offers a foundation to extra research in drug and useful applications.

Liposomes

Liposomes are round vesicles fabricated from lipid bilayers which can be often used to supply curcumin due to the fact they are able to encapsulate each lipophilic and hydrophilic medication. They are ideal for drug transport structures due to the fact they're non-poisonous and biocompatible. This section presents nanoparticle-based formulations of curcumin designed for enhanced therapeutic efficacy, particularly in targeted drug delivery and combination therapies. One notable formulation is the curcumin-loaded thermosensitive magneto liposomes, created through a thin film hydration method.

This formulation incorporates L-alpha phosphatidylcholine, Pluronic block copolymer (P123), and Fe3O4 nanoparticles, achieving an encapsulation efficiency of 81±3% for curcumin and 65±5% for Fe3O4 nanoparticles. The formulation exhibits thermosensitive drug release, with higher release rates at 43°C, making it suitable for combined chemotherapy and hyperthermia treatments. Another formulation, EGF-conjugated liposomes containing curcumin, targets pancreatic cancer cells. The conjugation with epidermal growth factor (EGF) enhances cellular uptake through EGFR-mediated mechanisms, resulting in higher cytotoxicity and improved anti-tumor activity. These formulations illustrate the potential of nanoparticle-based curcumin delivery systems in improving drug bioavailability, achieving targeted delivery, and facilitating synergistic therapies for cancer treatment.

Niosomes

Niosomes are non-ionic surfactant-based vesicular systems that offer several advantages over liposomes, particularly in terms of stability and cost-effectiveness.

Curcumin-loaded niosomes have been studied for their ability to deliver curcumin to cancerous tissues with enhanced cellular uptake. This study comprises of niosomal nanoparticles for treatments used to deal with neurological situations and afflictions.

A modified warming framework and a three-factor, three-degree composite recreation plan are utilized in one organizing, referred to as the chitosan-advanced curcumin-stacked niosome (CH-CLN), to make certain its readiness. With a particle size of around 100 nm, a polydispersity record (PDI) of 0.2 and an encapsulation viability of 75%, this enumerating is shown by strong light dispersing (DLS), zeta potential, FTIR, HPLC, and TEM.

It is a promising choice for conquering the blood-mind obstruction (BBB) in the treatment of neurodegenerative illnesses since it displays upheld release and an expansion in curcumin obsession inside the central tactile framework (CNS) after intraperitoneal mixture.

Another detail centers around antitumor and quieting medicines by incorporating non-ionic surfactants like Tween 85 with curcumin-stacked niosome nanoparticles, which are organized utilizing microfluidic mixing. With an epitome capability of around 60%, this plan shows a lipid-based bilayer structure, monodispersity (PDI 0. 07-0.3), and controlled release. These qualities feature the capability of niosomal nanoparticle structures for designated, helped drug conveyance and for defeating natural hindrances in the treatment of perplexing ailments.

Nanofibers

Nanofibers are a unique drug delivery system that has been explored for the controlled release of curcumin, particularly for its sustained release and stability properties.

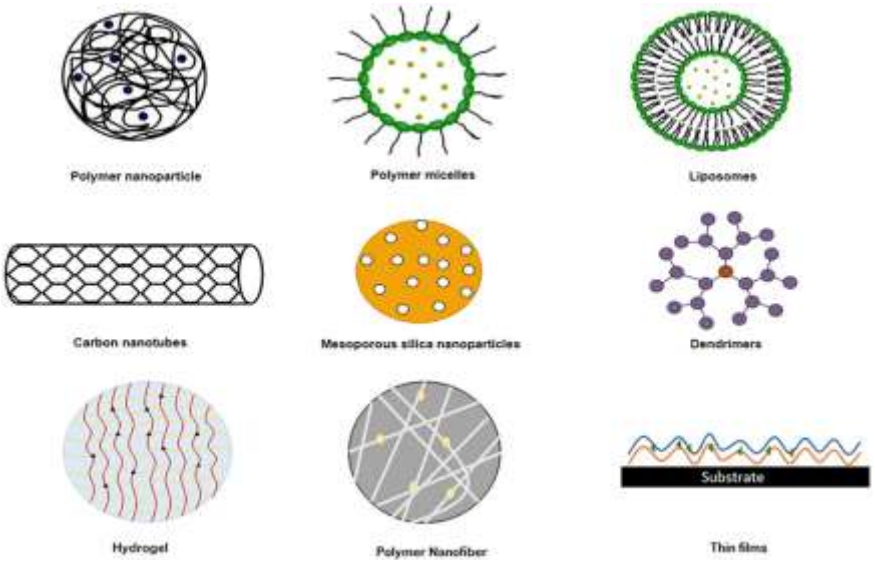

Fig 10: Curcumin Loaded Nanofibres

Emulsion & Nano-emulsion

Emulsion and nanoemulsion systems are colloidal dispersions of oil in water or water in oil, offering an effective strategy for improving the solubility and bioavailability of curcumin.

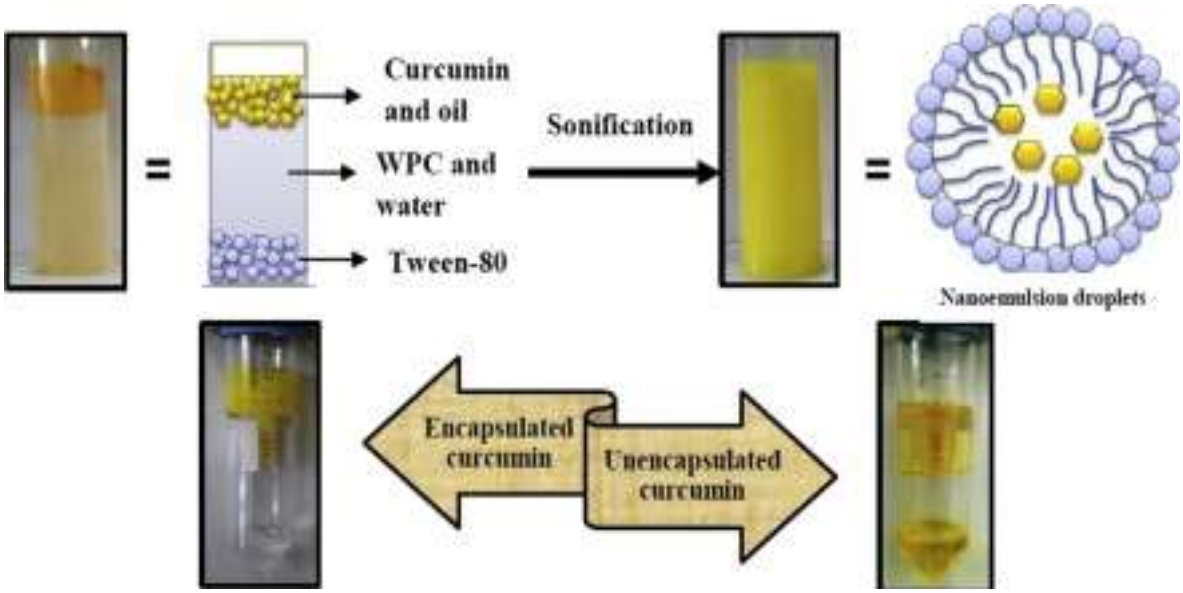

Fig 11: Curcumin loaded Nano-emulsion

Mechanism and Formulation Strategies: Emulsions and nanoemulsions typically consist of an oily phase (containing curcumin), a surfactant, and an aqueous phase. Nanoemulsions have smaller droplet sizes (below 200 nm), which enhances the solubility and absorption of curcumin. The formulation process includes methods like high-pressure homogenization, microfluidization, and solvent diffusion.

Advantages for Solubility Enhancement: Nanoemulsions improve the solubility of curcumin by reducing its particle size and enhancing its surface area. This results in better intestinal absorption and bioavailability.

Table 6: Emulsion and Nano-emulsion Containing Curcumin

Formulation	Technique Involved	Polymer Used	Application	Attributes	References
Pickering Emulsions (ZEIN/TA/GA Nanoparticles)	Zein nanoparticles, Tannic acid (TA) for cross-linking, Glycyrrhizic acid (GA) as a pH-responsive substance, Encapsulation of Curcumin, In vitro digestion study	Zein, Tannic acid (TA), Glycyrrhizic acid (GA)	Oral drug delivery, Intestine-targeted delivery system, Improving oral bioaccessibility of hydrophobic nutraceuticals	pH-responsive stability: stable in acidic conditions, demulsifies at neutral pH; High curcumin encapsulation efficiency; Protection from pepsin hydrolysis; Enhanced bioaccessibility of curcumin	Zhiqiang Li et al. 2023
Curcumin nanoemulsion	Wet ball milling method	Soybean oil, Tween 80 (stabilizer), water (dispersed medium), milling beads	Drug delivery system to increase curcumin solubility and bioavailability	Particle size ranging from 127-338 nm; High curcumin loading capacity; Stable for 60 days of storage; Simple and easy preparation method; Optimum milling time of 24 hours with 300 mg curcumin	ShobbuIbabasSholihat et al. 2020

Micelles

Micellar formulations have been extensively studied as a means to improve the solubility and bioavailability of curcumin, especially in oral and systemic delivery applications.

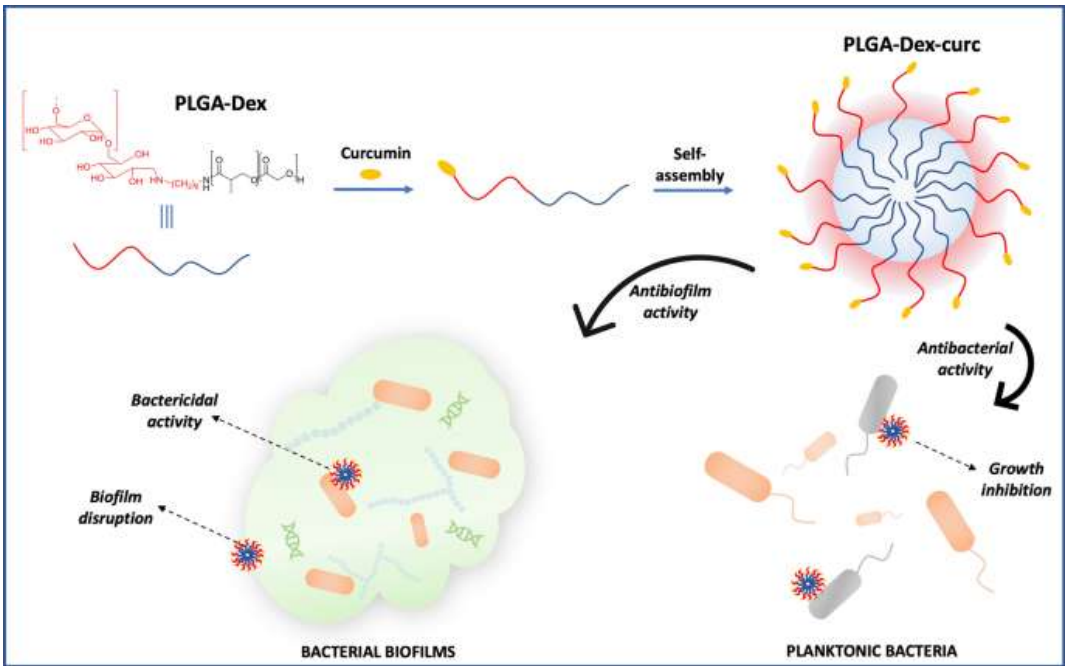

Fig 13: Curcumin Loaded Polymeric Micelles

Micellar Formulations for Enhancing Curcumin Solubility: Micelles are formed by surfactants that self-assemble in aqueous environments, encapsulating hydrophobic drugs like curcumin in their core. This increases curcumin's solubility in water and enhances its absorption.

Benefits in Bioavailability: The micellar delivery system not only improves the solubility of curcumin but also offers protection from enzymatic degradation and enhances its stability in biological fluids, thus improving its bioavailability.

Table 9: Micelles Containing Curcumin

Formulation	Technique Involved	Polymer Used	Application	Attributes	References
Curcumin-loaded polymeric micelles conjugated with folic acid	Fourier-transform infrared spectroscopy (FTIR), Transmission electron microscopy (TEM), Dynamic light scattering (DLS), MTT assay, Hemolysis assay	Polyethylene glycol (PEG), Polycaprolactone (PCL), Lysine linker	Curcumin delivery system with targeted cancer therapy	Biocompatible (hemolysis assay) Effective in vitro anticancer activity (MTT assay) Targeted drug delivery using folic acid conjugation No significant weight loss or side effects in vivo Good physicochemical properties for drug delivery	Mostafa Zamani et al. 2021
Oleylamine-coated SPIONs co-encapsulated with curcumin in TPGS:F127 mixed micelles	Thermal decomposition for SPION synthesis; mixed micelle formulation via encapsulation	d-α-Tocopheryl polyethylene glycol 1000 succinate (TPGS), Pluronic F127	Biomedical applications, sustained drug delivery	Average size ~84 nm, encapsulation efficiency (Cur: ~95%, SPIONs: ~56%), sustained release (10% Cur in 12h), high yield (>90%), sustained-release property	Ganeshlenin Kandasamy et al. 2019
Curcumin-loaded mPEG-PCL micelles	HNMR, FTIR, DSC, GPC, DLS, AFM, In vitro release	mPEG-PCL, Curcumin	Cancer treatment (future potential)	Successful formation of smooth, spherical micelles, 88% encapsulation efficiency, sustained drug release profile, potential for cancer therapy	Hossein Danafar et al. 2014

Studies: This study examines the development and characterization of curcumin-loaded polymeric micelles for targeted drug delivery, with a focus on their application in cancer therapy. Various formulations, including folic acid-conjugated micelles, oleylamine-coated superparamagnetic iron oxide nanoparticles (SPIONs), and mPEG-PCL micelles, were evaluated for their biocompatibility, physicochemical properties, and therapeutic efficacy. The micelles demonstrated excellent encapsulation efficiency and stable, sustained release profiles, with curcumin acting as a potent anticancer agent. Folic acid conjugation enabled targeted delivery to cancer cells, enhancing therapeutic outcomes without significant systemic toxicity. Additionally, the formulations exhibited good in vitro anticancer activity, confirmed by MTT assays, and biocompatibility, as shown by hemolysis assays. SPION-based micelles further offered the advantage of magnetically guided drug delivery, potentially improving treatment precision. These curcumin-loaded micelle systems show promising potential for advancing cancer therapy by combining effective drug encapsulation, sustained release, and targeted delivery capabilities. Further research may optimize these formulations for clinical application, ensuring enhanced therapeutic efficacy and minimized side effects.

Gels, Hydrogels, and Nanogels

Gels, hydrogels, and nanogels have become popular in curcumin delivery, particularly for localized treatment, as they can provide sustained release, enhance solubility, and improve therapeutic effects.

Differences and Applications for Curcumin Delivery: Gels and hydrogels are colloidal systems that can be used for topical and transdermal curcumin delivery. Nanogels, due to their nanoscale size, offer enhanced drug loading capacity and stability. Hydrogels are typically water-swollen polymers, whereas nanogels are crosslinked nanostructures.

Sustained Release and Localized Application Advantages: These systems can provide controlled drug release over extended periods, making them ideal for chronic treatments or for localized application to the skin. For example, curcumin-loaded hydrogels have been used for wound healing and skin disorders.

Table 10: Gels, Hydrogels and Nanogels Containing Curcumin

Formulation	Technique Involved	Polymer Used	Application	Attributes	References
Bovine Serum Albumin (BSA)-Oxidized Gellan (OxG) Hydrogel Films with Curcumin-β-Cyclodextrin (β-CD–Curc) Complex	Cross-linking, FT-IR, NMR, SEM, swelling degree, skin permeability study	Bovine serum albumin (BSA), oxidized gellan (OxG), β-cyclodextrin (β-CD), curcumin (Curc)	Biomedical applications, drug delivery system for curcumin	Non-toxic, biodegradable, biocompatible; enhanced curcumin solubility and bioavailability; controlled release at pH = 5.5, better film adhesion, and improved antioxidant activity.	Marcel Popa et al. 2024
Curcumin-loaded gum arabic aldehyde-gelatin (GA Ald-Gel) nanogels	Dynamic Light Scattering (DLS), NMR Spectroscopy, Scanning Electron Microscopy (SEM), MTT assay, Confocal Laser Scanning Microscopy (CLSM), In vitro drug release studies	Gum arabic aldehyde (GA Ald), Gelatin	Cancer therapy, curcumin delivery to MCF-7 cells	Hydrodynamic diameter: 452 ± 8 nm Zeta potential: −27 mV Encapsulation efficiency: 65 ± 3% In vitro toxicity observed in MCF-7 cells Cellular uptake confirmed by CLSM Potential for controlled drug release Hemocompatibility and cytocompatibility	Rachel James Nirmala et al. 2016

Studies: This study explores the development of advanced curcumin-loaded nanogel systems for targeted cancer therapy, focusing on two different formulations: bovine serum albumin (BSA)-oxidized gellan (OxG) hydrogel films with curcumin-β-cyclodextrin (β-CD–Curc) complex and gum arabic aldehyde-gelatin (GA Ald-Gel) nanogels. These formulations aim to enhance curcumin solubility, bioavailability, and targeted drug delivery.

The BSA-OxG hydrogel films were characterized as non-toxic, biodegradable, and biocompatible, with the ability to control curcumin release at acidic pH, making them suitable for biomedical applications. Furthermore, the gum arabic aldehyde-gelatin nanogels exhibited promising characteristics, including hydrodynamic diameters of 452 nm, a zeta potential of −27 mV, and a 65% encapsulation efficiency.

In vitro studies confirmed their toxicity in MCF-7 cancer cells, cellular uptake, and the potential for controlled drug release. Additionally, both formulations demonstrated cytocompatibility and hemocompatibility, indicating their safety for clinical applications. These results suggest that curcumin-loaded nanogel systems are highly effective for cancer treatment and may be developed further for clinical use in controlled drug delivery systems with minimized side effects.

Microspheres
Microspheres are spherical particles that are used for controlled and sustained release of curcumin, allowing for targeted delivery and minimizing side effects.

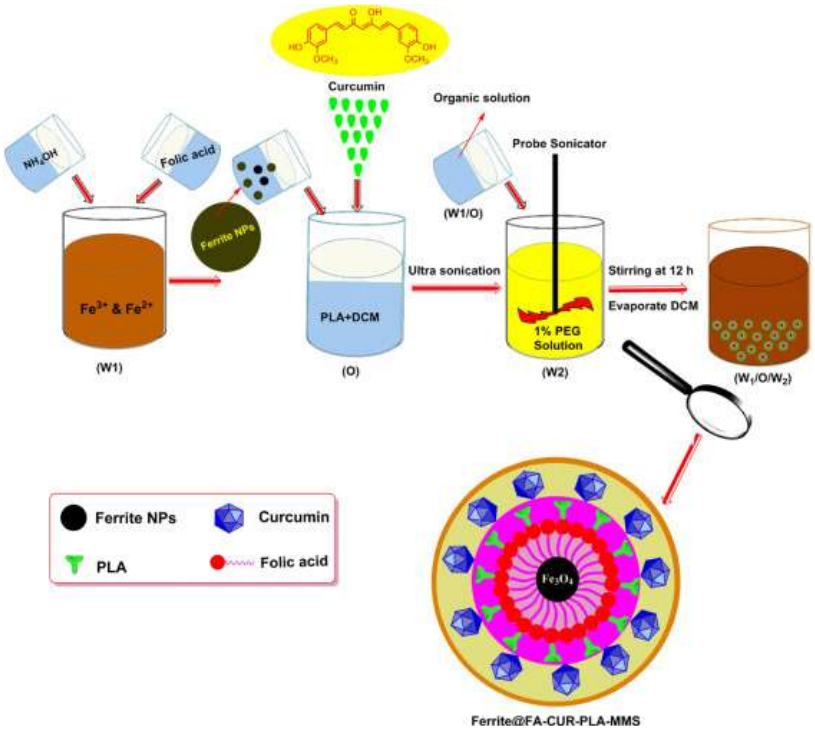

Fig 14: Curcumin Loaded Microsphere

Table 11: Microspheres Containing Curcumin

Formulation	Technique Involved	Polymer Used	Application	Attributes	References
Curcumin Loaded Zein Microspheres	Built-in ultrasonic dialysis process (BUDP) Zein as the polymer material	Zein	Controlled release of curcumin Encapsulation in zein microspheres	Particle size (Dp50): 431.2 ± 69.6 nm to 2335 ± 406.1 nm Optimized particle size: 398.2 ± 41.3 nm Spherical morphology FT-IR, NMR, XRD, TG, and DSC analysis confirm structural similarity to raw zein Successful in vitro sustained curcumin release	Guijin Liu et al. 2016

Studies: This study investigates the development of curcumin-loaded zein microspheres using a built-in ultrasonic dialysis process (BUDP) for controlled release. Zein, a natural protein, was employed as the polymer material to encapsulate curcumin and enhance its stability and bioavailability. The microspheres exhibited a particle size range from 431.2 ± 69.6 nm to 2335 ± 406.1 nm, with an optimized size of 398.2 ± 41.3 nm, and displayed spherical morphology. Comprehensive characterization through FT-IR, NMR, XRD, TG, and DSC analyses confirmed that the microspheres retained structural similarities to raw zein. In vitro release studies demonstrated the ability of the microspheres to provide sustained curcumin release, making them promising candidates for controlled drug delivery applications. These findings highlight the potential of zein microspheres as an effective delivery system for curcumin, with favorable properties for therapeutic use, especially in addressing challenges related to curcumin's solubility and stability.

CONCLUSION

The advancement of curcumin delivery through nanocarriers has shown immense promise in overcoming its inherent limitations, such as poor bioavailability and instability, thereby enhancing its therapeutic potential. A wide array of innovative nanoparticle-based systems has been explored, each contributing to better solubility, stability, and targeted release of curcumin, making it more suitable for clinical applications, particularly in cancer, neurological, and cardiovascular treatments. Various nanoparticles, including loponite, carboxymethyl cellulose-based hydrogels, and super-

paramagnetic silica nanoparticles, have been successfully designed for curcumin delivery. These formulations not only improve drug stability and bioavailability but also enable targeted delivery, especially to cancer cells, demonstrating substantial in vivo efficacy. Thermoresponsive systems like poly(N-isopropylacrylamide)-modified halloysite also offer controlled drug release, opening new possibilities for temperature-sensitive clinical applications. Liposomes, such as thermosensitive magneto liposomes and EGF-conjugated variants, show promising controlled release properties, particularly in the treatment of pancreatic cancer. Additionally, niosomes, including curcumin-loaded chitosan formulations, provide an effective means of overcoming the blood-brain barrier (BBB), presenting a significant advantage in neurological treatments by improving curcumin's bioavailability and stability. Curcumin-loaded composite films, like TiO2/curcumin/hydroxypropyl-cyclodextrin and curcumin-zein-EGCG-carrageenan films, provide controlled release and possess strong antibacterial properties. These films hold potential for both therapeutic and food packaging applications, underscoring their versatility in various industries.

REFERENCES

[1]. Gupta SC, Prasad S, Kim JH, Patchva S, Webb LJ, Priyadarsini IK, et al. Multitargeting by curcumin as revealed by molecular interaction studies. Nat Prod Rep. 2011;28(12):1937–55. DOI: 10.1039/c1np00051a. PMCID: PMC3604998.
[2]. Aggarwal BB, Yuan W, Li S, Gupta SC. Curcumin-free turmeric exhibits anti-inflammatory and anticancer activities: Identification of novel components of turmeric. Mol Nutr Food Res. 2013;57(9):1529-1542. https://doi.org/10.1002/mnfr.201200838
[3]. Ammon HP, Wahl MA. Pharmacology of Curcuma longa. Planta Med. 1991;57(1):1-7. https://doi.org/10.1055/s-2006-960004
[4]. Goel A, Kunnumakkara AB, Aggarwal BB. Curcumin as "Curecumin": From kitchen to clinic. BiochemPharmacol. 2008;75(4):787-809. https://doi.org/10.1016/j.bcp.2007.08.016
[5]. Menon VP, Sudheer AR. Antioxidant and anti-inflammatory properties of curcumin. Adv Exp Med Biol. 2007;595:105-125. https://doi.org/10.1007/978-0-387-46401-5_3
[6]. Gupta SC, Patchva S, Aggarwal BB. Therapeutic roles of curcumin: Lessons learned from clinical trials. AAPS J. 2013;15(1):195-218. https://doi.org/10.1208/s12248-012-9432-8
[7]. Priyadarsini KI. The chemistry of curcumin: From extraction to therapeutic agent. Molecules. 2014;19(12):20091-20112. https://doi.org/10.3390/molecules191220091
[8]. Lao CD, Ruffin MT 4th, Normolle D, Heath DD, Murray SI, Bailey JM, et al. Dose escalation of a curcuminoid formulation. BMC Complement Altern Med. 2006;6:10. DOI: 10.1186/1472-6882-6-10. PMCID: PMC1434783.
[9]. Wang YJ, Pan MH, Cheng AL, et al. Stability of curcumin in buffer solutions and characterization of its degradation products. J Pharm Biomed Anal. 1997;15(12):1867-1876. https://doi.org/10.1016/S0731-7085(96)02024-9
[10]. Shishodia S, Sethi G, Aggarwal BB. Curcumin: Getting back to the roots. Ann N Y Acad Sci. 2005;1056:206-217. https://doi.org/10.1196/annals.1352.010
[11]. Aggarwal BB, Harikumar KB. Potential therapeutic effects of curcumin, the anti-inflammatory agent, against neurodegenerative, cardiovascular, pulmonary, metabolic, autoimmune and neoplastic diseases. Int J Biochem Cell Biol. 2009;41(1):40-59. https://doi.org/10.1016/j.biocel.2008.06.010
[12]. Anand P, Kunnumakkara AB, Newman RA, Aggarwal BB. Bioavailability of curcumin: Problems and promises. Mol Pharm. 2007;4(6):807-818. https://doi.org/10.1021/mp700113r
[13]. Thangapazham RL, Sharma A, Maheshwari RK. Multiple molecular targets in cancer chemoprevention by curcumin. AAPS J. 2006;8(3):E443-E449. https://doi.org/10.1208/aapsj080352
[14]. Baum L, Ng A. Curcumin interaction with copper and iron suggests one possible mechanism of action in Alzheimer's disease animal models. J Alzheimers Dis. 2004;6(4):367–77; discussion 443–9. DOI: 10.3233/jad-2004-6403.
[15]. Mythri RB, Bharath MMS. Curcumin: A potential neuroprotective agent in Parkinson's disease. Curr Pharm Des. 2012;18(1):91–9. DOI: 10.2174/138161212798918995.
[16]. Prasad S, Tyagi AK, Aggarwal BB. Recent developments in delivery, bioavailability, absorption and metabolism of curcumin: The golden pigment from golden spice. Cancer Res Treat. 2014;46(1):2-18. https://doi.org/10.4143/crt.2014.46.1.2
[17]. Nayak AP, Mills T, Norton I. Lipid-based nanosystems for curcumin: Past, present, and future. Curr Pharm Des. 2016;22(27):4247–56. DOI: 10.2174/1381612822666160614083412.
[18]. Hewlings SJ, Kalman DS. Curcumin: A review of its effects on human health. Foods. 2017;6(10):92. https://doi.org/10.3390/foods6100092
[19]. Ireson CR, Jones DJL, Orr S, Coughtrie MWH, Boocock DJ, Williams ML, et al. Metabolism of the cancer chemopreventive agent curcumin in human and rat intestine. Cancer Epidemiol Biomarkers Prev. 2002;11(1):105–11.
[20]. Metzler M, Pfeiffer E, Schulz SI, Dempe JS. Curcumin uptake and metabolism. Biofactors. 2013;39(1):14-20. https://doi.org/10.1002/biof.1070

[21]. Shoba G, Joy D, Joseph T, et al. Influence of piperine on the pharmacokinetics of curcumin in animals and human volunteers. Planta Med. 1998;64(4):353-356. https://doi.org/10.1055/s-2006-957450
[22]. Moballegh Nasery M, Abadi B, Poormoghadam D, et al. Curcumin delivery mediated by bio-based nanoparticles: A review. Molecules. 2021;26(3):689. https://doi.org/10.3390/molecules26030689
[23]. Umerska A, Gaucher C, Oyarzun-Ampuero F, Fries-Raeth I, Colin F, Villamizar-Sarmiento MG, et al. Polymeric nanoparticles for increasing oral bioavailability of curcumin. Antioxidants. 2018;7(4):46. DOI: 10.3390/antiox7040046.
[24]. Farhoudi L, Kesharwani P, Majeed M, Johnston TP, Sahebkar A. Polymeric nanomicelles of curcumin: Potential applications in cancer. Int J Pharm. 2022;617:121622. DOI: 10.1016/j.ijpharm.2022.121622.
[25]. Loftsson T, Masson M. Cyclodextrins in topical drug formulations: Theory and practice. Int J Pharm. 2001;225(1-2):15-30. https://doi.org/10.1016/S0378-5173(01)00711-0
[26]. Falconieri MC, Adamo M, Monasterolo C, Bergonzi MC, Coronnello M, Bilia AR. New dendrimer-based nanoparticles enhance curcumin solubility. Planta Med. 2017;83(5):420–5. DOI: 10.1055/s-0042-103161.
[27]. Hamad I, Harb AA, Bustanji Y. Liposome-based drug delivery systems in cancer research: An analysis of global landscape efforts and achievements. Pharmaceutics. 2024;16(3):400. DOI: 10.3390/pharmaceutics16030400.
[28]. Dadhaniya P, Patel C, Muchhara J, et al. Safety assessment of a solid lipid curcumin */particle preparation: Acute and subchronic toxicity studies in rats. Food Chem Toxicol. 2011;49(8):1834-1842. https://doi.org/10.1016/j.fct.2011.04.012
[29]. Ghoran SH, Calcaterra A, Abbasi M, Taktaz F, Nieselt K, Babaei E. Curcumin-based nanoformulations: A promising adjuvant towards cancer treatment. Molecules. 2022;27(16):5236. DOI: 10.3390/molecules27165236. PMCID: PMC9414608.
[30]. Sideek SA, El-Nassan HB, Fares AR, ElMeshad AN, Elkasabgy NA. Different curcumin-loaded delivery systems for wound healing applications: A comprehensive review. Pharmaceutics. 2022;15(1):38. DOI: 10.3390/pharmaceutics15010038.
[31]. Sun Q, Lv M, Li Y. Nanotechnology-based drug delivery systems for curcumin and its derivatives in the treatment of cardiovascular diseases. J Funct Foods. 2024;122:106476. DOI: 10.1016/j.jff.2024.106476.
[32]. Gayathri K, Bhaskaran M, Selvam C, Thilagavathi R. Nano formulation approaches for curcumin delivery- a review. J Drug Deliv Sci Technol. 2023;82:104326. DOI: 10.1016/j.jddst.2023.104326.
[33]. Nayak AP, Mills T, Norton I. Lipid-based nanosystems for curcumin: Past, present, and future. Curr Pharm Des. 2016;22(27):4247–56. DOI: 10.2174/1381612822666160614083412.
[34]. Patel P, Garala K, Singh S, Prajapati BG, Chittasupho C. Lipid-based nanoparticles in delivering bioactive compounds for improving therapeutic efficacy. Pharmaceuticals. 2024;17(3):329. DOI: 10.3390/ph17030329.